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A biofuel strategy for Ireland with an emphasis on production of biomethane and minimization of land-take

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ABSTRACT

Increasing energy consumption has exerted great pressure on natural resources; this has led to a move towards sustainable energy resources to improve security of supply and to reduce greenhouse gas emissions. However, the rush to the cure may have been made in haste. Biofuels in particular, have a bad press both in terms of competition with good agricultural land for food, and also in terms of the associated energy balance with the whole life cycle analysis of the biofuel system. The emphasis is now very much on sustainable biofuel production; biofuels from wastes and lignocellulosic material are now seen as good sustainable biofuels that affect significantly better greenhouse gas balances as compared with first generation biofuels. Ireland has a significant resource of organic waste that could be a potential source of energy through anaerobic digestion. Ireland has 8% of the cattle population of the EU with less than 1% of the human population; as a result 91% of agricultural land in Ireland is under grass. Residues such as slurries and slaughter waste together with energy crops such as grass have an excellent potential to produce biogas that may be upgraded to biomethane. This biomethane may be used as a natural gas substitute; bio-compressed natural gas may then be an avenue for a biofuel strategy. It is estimated that a maximum potential of 33% of natural gas may be substituted by 2020 with a practical obtainable level of 7.5% estimated. Together with biodiesel from residues the practical obtainable level of this strategy may effect greater than a 5% substitution by energy of transport. The residues considered in this strategy to produce biofuel (excluding grass) have the potential to save 93,000 ha of agricultural land (23% of Irish arable land) when compared to a rapeseed biodiesel strategy.

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Abbreviations: AD, anaerobic digestion; CAD, centralised anaerobic digestion; CH_4, methane; CO_2e, carbon dioxide equivalent; DS, dry solids; GDP, gross domestic product; GHG, greenhouse gas; NCCS, National Climate Change Strategy; OFMSW, organic fraction of municipal solid waste; UCO, used cooking oil; VDS, volatile dry solids.

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1. Introduction

Sustainable development is a term that is now very trite in a number of waste management, energy generation and rural development plans [1]. Renewable energy sources have been growing in importance in the European and global energy markets due to various benefits associated with their use viz. decreasing import dependency, diversifying sources of production, and contributing to sustainable development [2]. A considerable reduction in energy dependency and carbon emissions could be achieved by using biofuels from organic waste.

1.1. Greenhouse gas targets

The European Commission (EC) proposed new emissions targets for 2020 in 2008/0014 (COD), dated 21/01/2008. These targets are proposed to replace the Kyoto targets when they expire in 2012; for Ireland this target is 20% less emissions relative to 2005 by 2020 [3]. Ireland has faced incredible difficulty in attempting to meet the Kyoto target which allowed a 13.5% increase in greenhouse gas (GHG) emissions above 1990 levels in the first commitment period (2008–2012). At present Ireland's GHG emissions stand at about 26% above the 1990 level [4].

1.2. Sustainability of biofuels

Sustainability of biofuels has come under scrutiny in the past years [5–8]. Fig. 1 highlights a comparative energy balance which indicates the relative gross and net energy production per hectare for various biofuel systems. It may be noted that traditional European indigenous biofuel systems (ethanol from wheat and rapeseed biodiesel) do not fare as well as tropical biofuel systems such as palm oil biodiesel. Biogas from grass may however be deemed a good biofuel as it generates an equivalent energy to palm oil biodiesel and does not threaten sensitive ecosystems. The EU responded with the Renewable Energy Directive [9] which stipulated that biofuels need to meet two criteria to be classified as biofuels after 2010, namely:

- To achieve a greenhouse gas emissions saving of at least 35% compared with the fossil fuel they replace on a life cycle analysis basis;
- not to be made from land with recognised high biodiversity value or high carbon stock.

The Directive [9] attributed some default values to biofuel systems, some of which are outlined below:

Wheat ethanol (process fuel not specified)	0%
Wheat ethanol (natural gas process fuel)	33%
Rapeseed biodiesel	36%
Palm oil biodiesel (process with no methane emissions to air at oil mill)	55%
Waste vegetable or animal oil biodiesel	77%
Biogas (as compressed biomethane) from various residues	75–85%

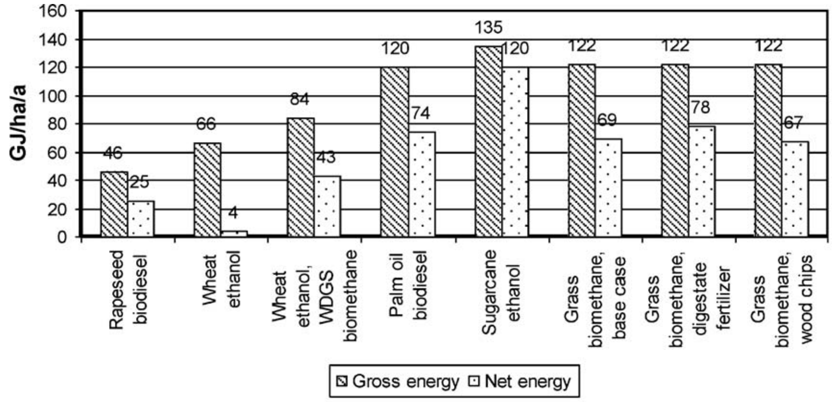
Thus the benefit of biogas and biodiesel when generated from residues such as the organic fraction of municipal solid waste (OFMSW) and agricultural residues is quiet obvious.

1.3. Biofuels from waste

Major economies are relying on biofuels as part of their strategies to reduce GHG emissions and energy dependency. For Ireland, biofuels from wastes can play an important role in improving the balance of trade by reducing imports of increasingly expensive fossil fuels. Unlike other renewable energy sources, the production and use of biofuels is relatively labour-intensive and can also potentially play a positive role in maintaining and developing the rural economy. Environmental pollution from municipal, industrial and agricultural operations/wastes continues to grow. The concept of the 'four R's', Reduce, Reuse, Recycle and Renewable energy, has generally been accepted as a useful principle for waste handling [10]. Municipal, industrial and agricultural wastes contain organic substances with significant energy potential that can be used efficiently with the help of technologies, such as anaerobic digestion (AD). This will provide the dual benefits of delivering energy and also protecting the environment.

1.4. Anaerobic digestion (AD)

Anaerobic digestion is an appropriate technique for converting organic wastes (slaughterhouse waste, agricultural slurries, the organic fraction of municipal solid waste, etc.) and wet biomass such as ensiled energy crops, into renewable energy. Digestion of organic wastes yields a substance that has a lower pollution



Sources: rapeseed and palm oil biodiesel [6]; wheat ethanol scenarios [5]; sugarcane ethanol [8].
Energy in agriculture subtracted from energy in wheat ethanol.
Grass biomethane, digester fertilizer: allows for substitution of mineral fertilizer with digestate.
Grass biomethane, wood chips: allows for use of wood chips as a thermal energy input with associated greater substitution sale of biomethane.

Fig. 1. A comparison of gross and net energy (GJ/ha/a) for a number of biofuel systems (from Smyth et al. [7]).

potential and is more suitable than raw wastes for use as fertilizer in agricultural production. In addition, the goal of a sustainable cropping system can be achieved since the digested residue can be used as a fertilizer [11]. The biogas produced can be used to generate heat and/or electricity or can be scrubbed to natural gas quality for use as transport fuel or injection into the natural gas grid.

1.5. Aims of the paper

The aim of the present study is to review relevant information necessary to determine the applicability of anaerobic digestion to biofuel production from wastes, along with the production of biodiesel from wastes. Accordingly, a description and quantification (along with potential for recovery and energy potential) of agricultural slurries, the organic fraction of municipal solid wastes, slaughter wastes, tallow and used cooking oil (UCO) is undertaken. The case is also made for the use of surplus grass as a feedstock for anaerobic digestion. It is likely that cattle numbers will decrease in the future, resulting in the availability of grassland previously under livestock.

1.6. Objectives of the paper

The objectives of this paper are outlined below:

- What is the potential and practical energy available from these feedstocks?
- How much of the transport fleet may be powered by these fuels?
- How much natural gas may be substituted?
- What portion of final energy may be generated from residues and grass expressed as a percentage of final energy demand for transport and final energy demand?
- What is the saving in land-take compared with alternative biofuel strategies using energy crops?

2. Energy use in Ireland

2.1. Growth in energy consumption in transport

Ireland has experienced high levels of energy demand growth in line with buoyant economic growth. Between 1990 and 2007 Ireland's total annual energy requirement grew in absolute terms by 70%. Fossil fuels accounted for 96% of all energy used in Ireland in 2007. Transport energy use grew by 180% over the period 1990–2007 (6.3% per annum). Ireland's total final energy consumption in 2007 was 13 Mtoe out of which transport consumed 5.7 Mtoe. Transport's share of total final energy consumption increased from 28% to 43% over the period 1990–2007. Residential, industry, agricultural and services experienced a drop in energy consumption over the same period [12].

2.2. Energy forecasts

Two separate energy forecasts (Baseline and White Paper) for Ireland are available. The Baseline forecasts Ireland's future energy trends, incorporating the anticipated impacts of policies and measures that were in place (provided for by legislation) by the end of 2007 [12]. Ireland's White Paper 'Delivering a Sustainable Energy Future for Ireland' [13] presents an alternative view of future energy trends that may occur if the key targets are met. The White Paper forecasts are more ambitious than the baseline forecasts. The projection of final energy demand for 2010 and 2020 shows that energy demand in transport is anticipated to grow very fast, while in other sectors it is anticipated to decrease. In both the Baseline and White Paper forecasts, final energy demand in transport is expected to increase respectively to 7.52 and 6.96 Mtoe, with energy in buildings (services and residential) accounting for 5.87 and 4.61 Mtoe and for industry 2.75 and 2.29 Mtoe, respectively by 2020 [12].

2.3. Energy in transport and biofuels

Energy consumption in the Irish transport sector was 225.75 PJ in 2006, which was 41.4% of the total final energy consumption in Ireland [14]. Biofuels penetration was only 0.05% in that year [15]. The Biofuels Directive 2003/30/EC [16] and Ireland's White Paper set a target of 5.75% biofuels market share in the transportation sector by 2010 and 10% by 2020 [13,16]. The Minister for Communications, Energy and Natural Resources has recently launched a public consultation paper on his proposals to introduce a Biofuels Obligation in 2010. This will require that a certain percentage of the road transport fuel sold in Ireland in 2010 will be renewable. Targets for biofuels for 2010 are likely to be dropped to 4% by volume rather than 5.75% by energy [17]. The target may be changed in the medium term to ensure that Ireland meets its renewable energy target for the transport sector by 2020 [18].

2.4. Biofuels and land-take

Only 9% of agricultural land in Ireland is arable; compared to 91% under grass [19]. Murphy and Power [20] have shown that Ireland would require 63% of arable land in the country to be under rapeseed each year to meet the Biofuels Directive (5.75% target) through rapeseed biodiesel alone. The 63% of arable land equates to 5.7% of all agricultural land, leading to the rule of thumb that 1% of agricultural land is required to satisfy 1% substitution of transport fuel with biofuels [6]. Increasing the land area under oilseed rape reduces the quantity of land available for food production and might also be in conflict with Council Regulation (EC) No. 1782/2003, which states that permanent pasture land must be maintained as such. Considering these interrelated factors, Ireland's biofuels target is not likely to be met by indigenous rapeseed [6].

3. Greenhouse gas emissions from different sectors

3.1. Sectors which produce the largest quantity of greenhouse gases

The emissions of greenhouse gases (GHGs) in Ireland in 2007 were 69 Mt CO_2 equivalent (CO_2e). Agriculture was the single largest contributor to overall emissions at 27% of the total followed by energy (22%) and transport (21%). In comparison emissions from waste are relatively low, at only 3% of the total [21], but still represent an area where significant reductions can be made.

3.2. GHG emissions from the agricultural sector

The main factors contributing to GHGs in agriculture are emissions from agricultural soils, enteric fermentation, manure management and biomass burning [22]. The share of GHGs from agriculture reduced to 27% in 2007 from 35% in 1990 and is projected to be approximately one quarter of total GHG emissions in 2020.

3.3. GHG emissions from the transport sector

Emissions from the transport sector increased very rapidly between 1990 and 2007; emissions in 2007 were 178% higher than in 1990. Transport GHG emissions are estimated to reach 107–117% of 2007 levels by 2020 [12,21]. This might be due to the significant increase in the number of vehicles and emissions per vehicle during this period. Emissions have increased almost threefold since 1990 while vehicle numbers increased only twofold. This is due to the dominance of the car in Irish society, the utilization of bigger cars with greater emissions per km, travelling longer distances and spending longer times in traffic jams.

3.4. GHG emissions from the waste sector

Emissions from waste increased by 33% during the period 1990–2007 [12,21] and if measures are not taken to treat/reuse the waste, emissions from waste will continuously increase. Council Directive 1999/31/EC [23] on the landfill of waste sets out targets for the diversion of biodegradable waste from landfill. The primary goal is to reduce dependence on landfill in favour of more environmentally sound alternatives. Ireland (and other EU states) is restricted to landfilling in 2010 no more than 75% of the equivalent total weight of biodegradable municipal waste produced in 1995, the baseline year. This target is further reduced to 50% of the 1995 baseline by 2013 and 35% by 2016 [24]. In 2007, the landfilling of biodegradable municipal waste was 15% above 1995 levels [4]. It is now increasingly urgent, given that the first target year is 2010, to find alternatives to landfill. Quantities of biodegradable municipal waste sent to landfill must be reduced by over 450,000 t by the start of 2010 [24]. Utilization of biodegradable waste for anaerobic digestion will provide biomethane (energy for various purposes) and reduced emissions from waste, and also fulfil the targets set out by The Landfill Directive.

4. Energy potential of wastes/residues and selected biomass

4.1. Overview

For the present study, agricultural slurries, the organic fraction of municipal solid waste, slaughterhouse waste, tallow, used cooking oil and surplus grass are considered for energy production. Other organic waste viz. sewage sludge and food beverage sludge are excluded; many larger sewage treatment plants already incorporate anaerobic digestion and use the produced biogas to generate combined heat and power (CHP) to satisfy some of the parasitic energy demands of the facility. Typically this biogas is not available for export outside the facility. The use of waste grass, such as grass from back gardens, verge cuttings and golf courses, is outside the scope of this study; information on these feedstocks is limited, the sources are widely distributed and much of this material is currently composted.

4.2. Agricultural slurries

Agriculture is the single largest source of waste in Ireland [25]. The organic agricultural wastes refer to all types of animal excreta (i.e. faeces and urine from cattle, sheep, pigs, and poultry) in the form of slurries and farmyard manures. The estimation of the quantity of agricultural waste is based on animal numbers, average waste production per animal and the length of time that animals are kept indoors. The manner with which the animal slurry calculation is conducted changes periodically; this makes it difficult to assess trends in waste production. The most reliable indicator for agricultural waste production is therefore animal numbers. For estimation of slurry production the average housing period of 20 and 6 weeks is considered for cattle and sheep, respectively. For pig and poultry it was assumed that all the slurries or litter produced are collected [26]. The quantity of slurry per head is calculated by dividing the slurry produced in 1998 by the number of livestock in the same year (Table 1; [27,28]). The number of livestock (cattle, pig and sheep) was taken from Donnellan and Hanrahan [29]. The average number of poultry was calculated using poultry numbers from 1991 to 2003 [27,28].

Total slurry production in Ireland is estimated as 34.89 Mt per annum and is dominated by cattle slurry (Table 2). The biogas potential of slurry/manure depends on several factors such as method of collecting slurry, total and volatile solid contents of the slurry and the degradation efficiency of the biogas plant. Brikmose [30] reported the biogas potential of cattle and pig slurry as 22 m_n^3 biogas per tonne of slurry. Tricase and Lombardi [31] reported 44.5 m_n^3 biogas production per tonne of poultry litter. The biogas production potential of sheep manure is calculated as 54.4 m_n^3 biogas per tonne (Box 1). The annual energy potential of

Table 1
Average slurry/manure production during housing by different livestock.

Livestock	Slurry produced (Mt) [26]	Number of heads[a] (M) [27,28]	Collectable slurry (t/a/head)
Cattle	37.10	7.30	5.08
Pig	2.62	1.81	1.45
Poultry	1.85	13.01	0.14
Sheep	0.34	6.94	0.05

[a] The livestock numbers are an average of June and December numbers.

Table 2
Total and practical energy potential of the slurry generated in Ireland.

	Cattle[a]			Pig[a]			Sheep[a]			Poultry[b]			Total		
	2007	2010	2020	2007	2010	2020	2007	2010	2020	2007	2010	2020	2007	2010	2020
Number of heads (M)	6.00	5.89	5.5	1.62	1.6	1.49	3.83	3.45	3.28	12.95	12	12	24.40	22.94	22.27
Slurry quantity (Mt/a)	30.51	29.95	27.97	2.35	2.32	2.16	0.19	0.17	0.16	1.84	1.70	1.70	34.89	34.14	31.99
Biogas[c] (Mm_n^3/a)	671.22	658.90	615.27	51.70	51.02	47.52	10.34	9.15	8.70	81.88	75.81	75.81	815.14	794.88	747.30
CH_4 production[c] (Mm_n^3/a)	369.17	362.39	338.40	28.44	28.06	26.13	5.68	5.03	4.78	45.03	41.70	41.70	448.32	437.19	411.01
Total[d] energy (PJ/a)	13.95	13.69	12.78	1.07	1.06	0.99	0.21	0.19	0.18	1.70	1.58	1.58	16.94	16.52	15.53
Practical energy (PJ/a)	0.14	0.27	0.64	0.01	0.02	0.05	0.002	0.004	0.01	0.00	0.79	1.18	0.15	1.09	1.88

[a] Donnellan and Hanrahan [29].
[b] The number of poultry for year 2007 is an average of poultry numbers present during 1991–2003 [27,28], as the data for number of poultry is not available after 2003. The number of heads varied in between 11 and 13 M during the period, so it is assumed that poultry heads will be constant at 12 M for 2010 and 2020.
[c] Biogas potential of 1 t cattle, pig, sheep and poultry slurry is 22, 22, 54.4 and 44.5 m_n^3 biogas, respectively, having 55% methane.
[d] CH_4 has energy value of 37.78 MJ/m_n^3.

agricultural slurry generated in Ireland is 16.94 PJ (Table 2); this is based on the energy value of methane (CH_4) of 37.78 MJ/m_n^3 [35].

Donnellan and Hanrahan [29] made projections for livestock numbers in Ireland up to 2017 on an annual basis. If projected heads for 2017 are taken as a constant figure for the future, then animal populations of 5.5 M cattle, 1.49 M pigs and 3.28 M sheep are assumed for 2020. There is no forecast for poultry production in Ireland; as poultry population has varied between 11 and 13 million during the period 1991–2003, it is assumed that poultry population will remain constant at 12 million birds. On the basis of these projections, Ireland has the potential to produce 16.52 and 15.53 PJ of energy in 2010 and 2020, respectively from the anaerobic digestion of agricultural slurry (Table 2). Brown [36] mentioned in the report 'Bioenergy in Ireland' that 0.1% of cattle and pig slurry was used in anaerobic digestion during 2001. Brown also assessed for the years 2010 and 2020 the practical availability of slurries for digestion. The values quoted are (2010 figures followed by 2020 figures):

- 2% and 5% for cattle and pig slurry;
- 50% and 75% for poultry slurry.

The percentage quantity of sheep slurry available for anaerobic digestion is taken as similar to that of cattle and pig slurry. On the basis of these assumptions, the practical possibility to generate energy from agricultural slurry is 1.09 and 1.88 PJ during the years 2010 and 2020, respectively (Table 2).

4.3. Organic fraction of municipal solid waste (OFMSW)

Biodegradable municipal waste (BMW) is the fraction of municipal waste that can undergo biological decomposition and is typically composed of food and garden waste, wood, paper, cardboard and textiles. The organic fraction of municipal solid waste comprises food and garden waste only. The rate of municipal waste generation is closely linked to gross domestic product (GDP) and personal consumption, while it is less closely linked to the population growth [24]. Forecasts for GDP are available from The Economic and Social Research Institute [37]; however, forecasts are only until 2015 and were published in May 2008 prior to the rapid deterioration of the global and national economy. For the purposes of this study, the quantity of OFMSW is assumed to increase linearly with increasing population. Population estimates were taken from Central Statistics Office data [38] and used to calculate projected OFMSW in 2010 and 2020, i.e. approximately 0.81 Mt for 2010 and 0.87 Mt for 2020 (Table 3). Projections are based on the 779,015 t of OFMSW managed in 2006 [24]; more recent figures are available for 2007 [39], but include oils and fats which are dealt with separately in this analysis.

Box 1. Biogas production from sheep manure.

1 t of sheep manure @ 61.4% DS[a]	614 kg DS
VDS @ 54.9% of DS[a]	337 kg VDS
Biogas yield @ 0.19 m^3/kg VDS[b]	
@85% degradation efficiency of plant[c]	54.4 m_n^3 biogas

[a]From [32]; [b]from [33]; [c]from [34]; DS, dry solids; VDS, volatile dry solids

Under Council Directive 1999/31/EC, targets are set to divert biodegradable waste from landfill. However, the recovery and recycling of biodegradable and organic waste is disappointing and the 2006 National Waste Report [24] notes that the separate collection and diversion from landfill of organic waste needs to be accelerated. From 2006 to 2007 the quantity of biodegradable municipal waste disposed of to landfill in Ireland increased by 4% to 1.48 Mt, moving Ireland further from the first Landfill Directive target of less than one million tonnes of biodegradable municipal waste to be landfilled in 2010 [24]. In 2006 the quantity of OFMSW collected in Ireland was 779,015 t (excluding edible fats and oils). Only 7.1% of the collected OFMSW was recovered, while the remaining 92.9% was sent to landfill. Of the organic waste recovered in 2006, almost three quarters was garden and park waste and just over a quarter biodegradable kitchen and canteen waste [24].

Digestion of OFMSW has received increased attention since the early 1990s, with the development of both commercial and pilot anaerobic digestion plant designs in many countries worldwide [40]. However, there are currently no dedicated plants for the anaerobic digestion of OFMSW in Ireland, despite its potential for energy and compost (digestate) production. The relative benefits of anaerobic digestion and composting have been discussed by Murphy and Power [41], who concluded that anaerobic digestion is a more beneficial than composting for the treatment of organic wastes in terms of GHG reduction. AD with biomethane production has the potential to save 1451 $kgCO_2e$/t of bio-waste treated as opposed to composting, which has the potential to save 1190 $kgCO_2e$/t [41].

Table 3
Energy potential of biogas from OFMSW.

Details	2006	2010	2020
Population[a] (M)	4.23	4.38	4.74
OFMSW production[b] (Mt)	0.78	0.81	0.87
Biogas yield[c] (Mm_n^3)	97.38	100.84	108.93
Methane yield[c] (Mm_n^3)	53.56	55.46	59.91
Theoretical energy (37.78 MJ/m_n^3) (PJ)	2.02	2.10	2.26
Recoverable quantity to AD (%)	0	0	25
Practical energy (PJ)	0	0	0.57

[a] Population estimates are from CSO projections [38] using Method M0F1 (total fertility rate to remain at 2006 level and zero net migration assumed).
[b] OFMSW is assumed to grow at the same rate as population. 2006 figure for OFMSW is from EPA National Waste Report [24].
[c] The biogas potential of one tonne OFMSW is 125 m_n^3, having 65% methane [36,41].

Table 4
Percentage breakdown of components of bovines in a slaughter facility.

Country	Meat	Rendered materials	Hide	Offal	Waste	Reference
Austria	36.2	22.5	8.3	3.2	29.8	[46]
Denmark	40	39[a]	7	5	9	[47]
USA	37–45[b]		4		51–59[c]	[48]
Value used for Ireland	36.2	22.5	8.3	3.2	29.8	

[a] Inedible materials bone, fat, head, condemned offal, etc.
[b] Cattle slaughtered under and over 30 months old.
[c] All waste except hide.

Previously SEI [36] estimated that 25% of OFMSW would be recoverable to anaerobic digestion in 2010 and 50% in 2020; landfill rates were predicted to be 25% in 2010 and 15% in 2020, with composting also playing a role in the treatment of OFMSW. However, the quantity of OFMSW diverted from landfill has been much lower than anticipated (the landfill rate in 2007 was 92%), and the majority of recovered OFMSW is sent for composting. Bearing in mind actual recovery rates, the current dominance of composting and lack of AD facilities, and lead-in times for planning and construction of AD plants, it is estimated that the quantity of OFMSW recovered to AD in 2010 will remain at 0%. Taking into account the advantages of AD over composting, targets to reduce OFMSW going to landfill and previous energy estimates, it is assumed that 25% of OFMSW will be digested in 2020 (which was the previous estimate for 2010 [36]). These levels could produce 0 and 0.57 GJ energy in 2010 and 2020, respectively (Table 3).

4.4. Slaughter waste

Ireland has 8% of the total bovine livestock in the EU-27 [42] but, at approximately 4.2 million people [43], less than 1% of the human population [44]. Every year in Ireland approximately 8 million livestock (mainly cattle, pigs and sheep) and 12 million poultry are slaughtered for meat production. The slaughtering process produces large quantities of organic waste that have the potential for methane production by anaerobic digestion [45]. The mass balance of livestock slaughtering in Austria [46], Denmark [47], USA [48] and the values used for this study are presented in Table 4. The mass balance data of Austria was found most useful by the authors; the Danish figures grouped rendering material with condemned offal while the figures from the USA summed all the waste. Waste products from the slaughter industry that may be digested and applied to non-pasture land in accordance with the

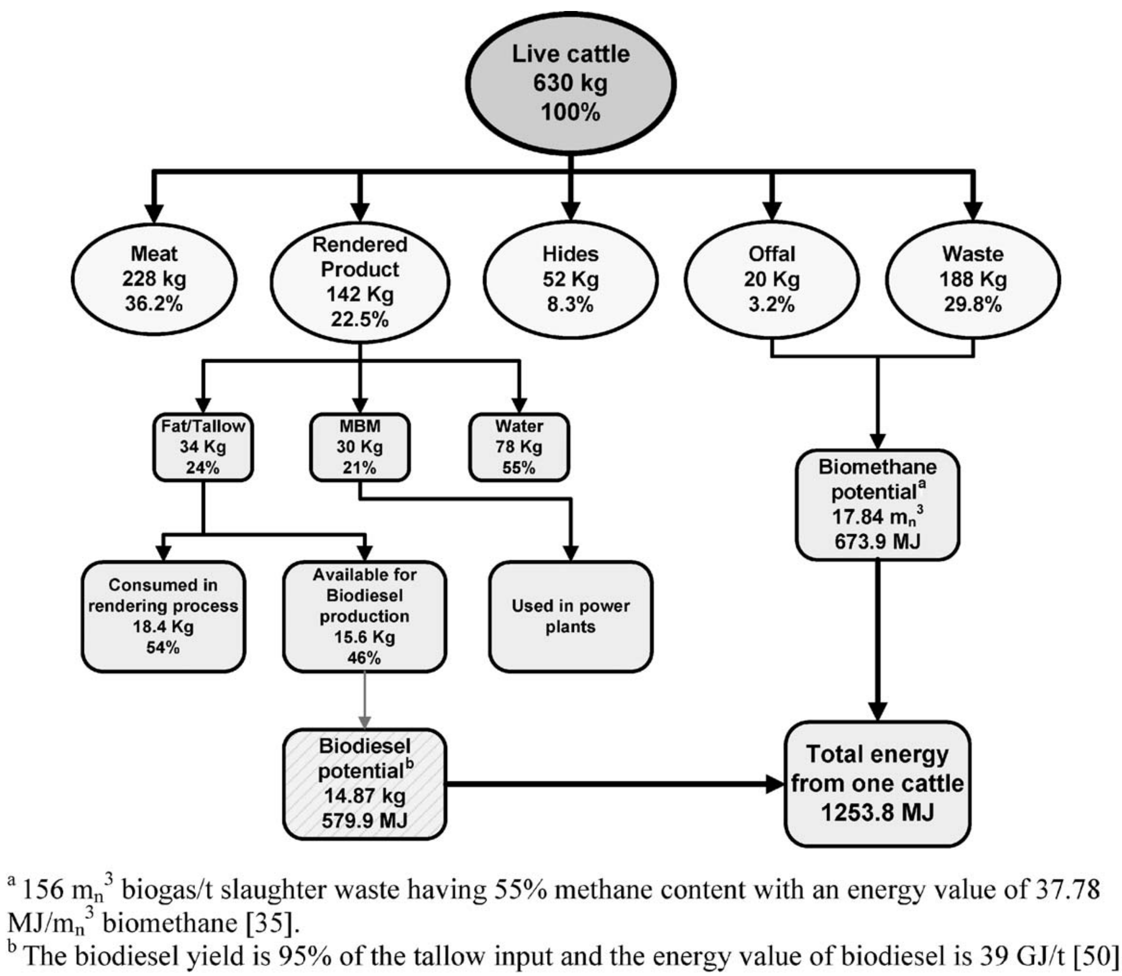


Fig. 2. The mass balance and energy potential of waste generated by the slaughtering of one bovine. (a) 156 m^3 biogas/t slaughter waste @ 55% methane; energy value of methane is 37.78 MJ/m^3 [35]. (b) Biodiesel yield is 95% of tallow input; energy value of biodiesel is 39GJ/t [50].

Table 5
Energy potential of slaughter waste in Ireland.

	Cattle			Pig			Sheep			Poultry			Total		
	2007	2010	2020	2007	2010	2020	2007	2010	2020	2007	2010	2020	2007	2010	2020
Number of heads[a] (M)	1.78	1.67	1.59	2.62	2.60	2.47	3.26	2.74	2.85	12.95	12.00	12.00	20.61	19.01	18.91
Slaughter waste (Mt)	0.37	0.35	0.33	0.07	0.07	0.07	0.02	0.02	0.02	0.007	0.006	0.006	0.47	0.44	0.42
Biogas potential (Mm_n^3)	57.76	54.19	51.59	11.04	10.95	10.40	3.51	2.95	3.07	0.74	0.69	0.69	73.04	68.77	65.75
Methane potential (Mm_n^3)	31.77	29.80	28.38	6.07	6.02	5.72	1.93	1.62	1.69	0.41	0.38	0.38	40.17	37.83	36.16
Total energy potential (PJ)	1.20	1.13	1.07	0.23	0.23	0.22	0.07	0.06	0.06	0.02	0.01	0.01	1.52	1.43	1.37
Practical energy potential (PJ)	0.00	0.00	0.54	0.00	0.00	0.11	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.68

[a] Number of head slaughtered (cattle, pig and sheep) from Donnellan and Hanrahan [29] for 2007 and 2010 and for year 2020 the projections of Donnellan and Hanrahan [29] for 2017 used. The number of poultry slaughtered is taken as the number of poultry produced.

Animal By-products Regulations [49] include rumen, stomach, intestinal content, animal low-risk waste and blood. The mass balance and energy potential (from [35,50]) of the waste generated in the slaughtering of live cattle is presented in Fig. 2. The offal and waste generated would be suitable for biogas production; this is equivalent to 208 kg/cattle. Murphy et al. [35] reported that 27 kg of slaughter waste per pig would be suitable for biogas production. The slaughtering of a sheep generates 12% stomach content [51] and 0.6% blood [52] as a percentage of live weight. Accordingly, sheep slaughtering generates 12.6% slaughter waste of live weight, which can be used for anaerobic digestion. The average live weight of a sheep/lamb is 55 kg [53], producing 6.9 kg waste per head. The British Columbia Ministry of Environment [53] reported that the slaughtering of an average broiler chicken produced 0.51 kg of solid waste. The production of slaughter waste is calculated by multiplying of number of heads slaughtered by the slaughter waste produced per head; data is presented in Table 5.

Murphy et al. [35] reported that 156 m_n^3 biogas can be produced from a tonne of cattle or pig slaughter waste. For this study the same biogas potential for sheep slaughter waste is considered. Salminen and Rintala [54] found that up to 140 m_n^3 methane can be generated from 1 t of poultry slaughter waste; for this study 112 m^3 methane per tonne of poultry slaughter waste is considered, this figure is more consistent with commercial scale. On the basis of these assumptions Ireland has potential to generate around 36 M m_n^3 methane, equivalent to 1.37 PJ energy in 2020 (Table 5).

Ireland requires eight biogas plants similar to Linkoping Biogas plant in Sweden. This facility in Linkoping digests about 46,000 t/a of slaughter waste and 7000 t/a agricultural slurry and produces 3.8 Mm_n^3 of biomethane for use in 65 buses, 600 cars, 10 waste collection lorries and a train. Presently Ireland does not have a single biogas plant, which can digest slaughter wastes. The practical energy potential is calculated by assuming that Ireland can develop four such plants by 2020, which will digest 50% slaughter waste and produce 0.68 GJ energy annually (Table 5).

4.5. Tallow

Tallow is a by-product of the slaughter industry and is produced by the rendering process, which is used to recycle raw material tissue from animals into value added products. Tallow production is linked to livestock production and, more specifically, to the number of livestock slaughtered. There are currently nine licensed rendering plants in Ireland and, in 2006, these plants processed 558,000 t of by-products to produce 88,000 t of tallow [55]. Information in the literature [50,56] states that 0.16 t of tallow is produced per tonne of processed material, which ties in with the 2006 figures (88,000/558,000 × 100 = 15.7%).

Tallow is a saleable product with a considerable market value attached (€160–170 t^{-1} in 2007, [55]) and potential purchasers of tallow for biodiesel have to compete with other industries. Depending on the category produced, markets for tallow include use in animal feed, soap manufacture, biodiesel production and in oleo-chemical industries. A significant quantity of tallow is also used as a substitute for mineral oil in the rendering industry in order to meet the heat demands of the rendering plants. In Ireland in 2003, 42,000 t of tallow (or 54% out of a total production of 78,000 t) was used as a substitute for mineral oil in the rendering industry, while a considerable portion of the remaining tallow is exported [56].

Future tallow production is estimated based on projected future numbers of animals slaughtered and the corresponding slaughter weights, taken from Teagasc projections [29]. The Teagasc projections are up to 2017 and, for the purposes of this analysis, the figures for 2017 are used for the 2020 scenario. The Teagasc data allows the calculation of carcass weights. From EC data [57] live weights are calculated from carcass weights, and from live weights, the quantity of by-products (35% of live weight) and hence the quantity of tallow (16% of by-products) is determined. Different methods are available for the calculation of the quantity of tallow produced from slaughter waste [46,50,56], but all give fairly similar results. The quantity of tallow in 2006 (93,000 t) from Table 6 is slightly higher than, but compares favourably with, the actual quantity produced (88,000 t); differences may be due to approximations in the calculations or losses of material between the slaughterhouse and rendering plant.

The biodiesel yield is 95% of the tallow input and the energy value of the biodiesel is 39 GJ/t [50]. The potential energy available from tallow is calculated as 1.59, 1.48 and 1.44 PJ for 2006, 2010 and 2020, respectively (Table 6). However, tallow already has a

Table 6
Energy potential of tallow for biodiesel production.

Source	Details	2006	2010	2020
Cattle	Carcass weight[a] ($t \times 10^3$)	574	537	506
	Average live weight[b] ($t \times 10^3$)	1063	994	937
Pigs	Carcass weight[a] ($t \times 10^3$)	209	198	188
	Average live weight[b] ($t \times 10^3$)	271	258	244
Sheep	Carcass weight[a] ($t \times 10^3$)	70	55	58
	Average live weight[b] ($t \times 10^3$)	144	113	117
Poultry	Carcass weight[a] ($t \times 10^3$)	130	131	139
	Average live weight[b] ($t \times 10^3$)	186	187	199
Tallow	Total live weight ($t \times 10^3$)	1664	1552	1497
	35% live weight as by-products ($t \times 10^3$)	583	543	524
	16% by-products as tallow ($t \times 10^3$)	93	87	84
	Tallow used in rendering plants ($t \times 10^3$)	50	47	45
	Tallow available for sale ($t \times 10^3$)	43	40	39
	Potential biodiesel ($t \times 10^3$)	40.85	38	37.05
	Potential energy (39 GJ/t) (PJ/a)	1.59	1.48	1.44
	Recoverable quantity to biodiesel[d] ($t \times 10^3$)	0	9[c]	19
	Biodiesel production (95%) ($t \times 10^3$)	0	8.55	18
	Practical energy (PJ/a)	0	0.333	0.715

[a] Donnellan and Hanrahan [29].
[b] Carcass weight of cattle, pig, sheep and poultry is 54, 77, 49 and 70% of live weight, respectively (average values in Europe [57]). Other minor meat sources such as horses, deer and goats have been omitted from the calculations.
[c] This is the expected quantity of tallow used in the sole current Irish plant.
[d] Tallow exported for biodiesel production abroad is neglected.

number of existing markets and therefore not all of the potentially available tallow is/will be sent for biodiesel production. In 2006, the quantity of tallow converted to biodiesel, and the resulting practical energy, was 0 GJ/a. Biodiesel produced from exported tallow is neglected. There is currently (May 2009) only one tallow-biodiesel plant in the country and it is assumed that it will remain the sole Irish plant in 2010. The plant plans to use about 9000 t/a of tallow (information from site visit), which is approximately 10% of the tallow produced in Ireland in 2006, resulting in an energy yield of 0.3 GJ/a (Table 6). The future use of tallow in biodiesel plants depends on the growth of the biodiesel industry in Ireland and also on tallow prices remaining competitive. The rendering industry works in a fast-changing regulatory environment, meaning forward planning is difficult [56]. Estimations of the quantity of tallow used for biodiesel in 2020 are therefore problematic and subject to considerable change. For this analysis, it is assumed that half of the tallow available for sale (19,000 t) will be converted to biodiesel in 2020, resulting in a practical energy of 0.715 GJ/a (Table 6). This is just over twice the tallow currently used for biodiesel in Ireland in the single existing plant. This plant has a present total capacity of around 30,000 t/a and therefore has the potential to increase the amount of tallow feedstock. The construction of one other biodiesel plant of a similar or smaller size to the existing plant would also allow the use of the assumed quantity of tallow in 2020.

4.6. Used cooking oil (UCO)

Used cooking oil, used vegetable oil (UVO) or recycled vegetable oil (RVO) is a product of catering in both domestic and commercial settings. Work by Thamsiriroj and Murphy [50] estimated that 5.2 kg/capita of used cooking oil is potentially recoverable per annum, but only two thirds of this (3.46 kg/capita/a) is realistically collectable. UCO is currently collected in Ireland, mainly from catering establishments and, in 2006, the quantity of recycled UCO was 9381 t [24], which is 64% of the estimated realistically collectable quantity (3.46 kg/capita/a $\times$ 4.2 million people). UCO can be recycled for a number of purposes, including use for biodiesel production, neat use in vehicles, use in oleo-chemical and cosmetic industries, and use in biogas or composting plants. In 2007, 2736 t of edible oils and fats were exported for use as fuel [39], while in 2006 the figure was higher at 4686 t (which was 50% of the collected UCO) [24]. Only a small percentage of UCO is composted [24]. Apart from the quantity exported for use as fuel, a breakdown of the volume of UCO recycled for other purposes is not provided in the National Waste Reports [24,39].

The production of UCO is dependent on population and also activity levels in the catering and hospitality sectors. The catering/hospitality sector is linked to general activity in the economy and in particular the tourism sector. Tourism has been previously used to determine potential trends in UCO supply [56]. However, due to difficulties with current economic projections, quantities of UCO are assumed to increase in line with population.

Population estimates from Central Statistics Office data are used to calculate projected UCO production in 2010 and 2020 (Table 7). Biodiesel yield is taken as 95% of UCO yield [50]. 2006 is used as the base year as more comprehensive data is available for that year than for more recent years. For 2006, UCO exported for use as fuel is neglected and the practical energy is calculated as zero. As of 2008, there is one plant producing biodiesel from UCO in Ireland. It is assumed that this will remain the sole plant in the country in 2010 and that the quantity of UCO used in the plant is the same as the quantity previously exported for use as fuel (50% of collected UCO). With better collection networks and waste management strategies, it is assumed that two thirds of the recoverable UCO (all the realistically collectable UCO) will be collected in 2020 and that 75% of this will be converted to biodiesel. A 100% recovery to biodiesel is considered unlikely due to competing industrial demands for UCO. The tallow/UCO biodiesel plant currently in operation in Ireland has a total current capacity of around 30,000 t/a and uses tallow, UCO and rapeseed as feedstock. The predicted quantity of biodiesel from tallow and UCO in 2020 (Tables 6 and 7) is approximately equivalent to the total current capacity of the plant, assuming only residues are used as feedstock. The practical energy from UCO biodiesel is calculated as 0.21 PJ in 2010 and 0.45 PJ in 2020 (Table 7).

Table 7
Energy potential of UCO.

	2006	2010	2020
Population[a] (M)	4.23	4.38	4.74
Recoverable UCO[b] (t)	22,011	22,796	24,624
Realistically collectable UCO[b] (t)	14,646	15,168	16,385
Potential biodiesel (95%) (t)	13,914	14,410	15,566
Potential energy (39 GJ/t) (PJ)	0.543	0.562	0.607
Quantity actually collected (% of recoverable)	43	49	67
Quantity actually collected (t)	9,381[c]	11,217	16,385
Quantity to biodiesel (%)	0	50	75
Quantity to biodiesel (t)	0	5,609	12,289
Practical energy (PJ)	0	0.208	0.455

[a] Population estimates from [38], see Table 3.
[b] Recoverable and collectable UCO per capita from [49].
[c] Quantity actually collected during the year 2006 is 64% of realistically collectable [24].

4.7. Surplus grass

The National Climate Change Strategy requires the Irish agricultural sector to reduce its GHG emissions by 2.4 Mt of CO_2e, with a further 2.08 Mt reduction coming from forest sinks [58]. The most recent NCCS [58] is not specific about how this is to be achieved, but the 2000 strategy [59] proposed reducing methane from cattle by the equivalent of a 10% reduction in the projected herd size for 2010. The 2000 strategy envisaged this target would be met by a balance between a decrease in the herd size, measures such as feeding regimes that lower emissions, and earlier finishing of animals [60]. As cattle are responsible for 86.6% of methane emissions from ruminant animals (1990), and 80% of the emissions from cattle come from non-dairy herds [59], the main target for herd reduction is likely to be in the beef sector.

Currently grass is grown on 3.94 Mha (more than 90% of agricultural land of Ireland) [19]. If the size of the national herd is reduced as set out in the NCCS, 0.39 Mha of agricultural grassland may be surplus to animal feed requirements by 2020. Smyth et al. [7] found that if grass is used for methane production it will provide 3240 m_n^3 CH_4/ha; this is equivalent to 122 GJ/ha/a of gross energy. On this basis, 0.39 Mha of surplus grass has the potential to generate 47.58 PJ/a energy. If only 25% of this area (0.1 Mha) was used in this industry in 2020, there is potential to generate 11.9 PJ energy (Table 8).

5. Proposed energy facilities for Ireland

5.1. International comparison of biogas/biomethane industry

Germany has 3500 digesters employing 10,000 people with a turnover in plant construction of €1 billion [61]. Austria with a population of about 8 million has around 600 digesters in total, including about 350 agricultural digesters [62,63], and has set a target of replacing 20% of natural gas used in the transport sector with biogas [64]. Germany has set a similar target. Sweden and Switzerland already have around 55% and 21% biomethane infiltration in the compressed natural gas vehicle fuel market

Table 8
Total energy potential of waste and surplus grass in Ireland for 2020.

Source	Potential Energy (PJ)			Practical energy (PJ)		
	Biodiesel	Biogas	Total	Biodiesel	Biogas	Total
Agricultural Slurry	0	15.53	15.53	0	1.88	1.88
OFMSW	0	2.26	2.26	0	0.57	0.57
Slaughter waste	0	1.37	1.37	0	0.68	0.68
Tallow	1.44	0	1.44	0.715	0	0.715
UCO	0.607	0	0.607	0.455	0	0.455
Surplus grass	0	47.58	47.58	0	11.9	11.9
Total	2.047	66.74	68.787	1.17	15.03	16.2
No. of cars fuelled (39 GJ/a/private car[a]) (M)	0.05	1.71	1.76	0.03	0.39	0.42
% of national fleet (1.88 M private cars)	2.8%	91.0%	93.8%	1.6%	20.5%	22.1%
% of total Irish Gas supply (4795 ktoe ≈201 PJ)		33.2%			7.5%	
% of final energy demand for transport in baseline scenario (5719 ktoe ≈315 PJ)	0.6%	21.2%	21.8%	0.4%	4.8%	5.1%
% of total final energy demand in baseline scenario (16,485 ktoe ≈690 PJ)	0.3%	9.7%	10.0%	0.2%	2.2%	2.3%
% of final energy demand for transport in white paper scenario (6958 ktoe ≈ 291 PJ)	0.7%	22.9%	23.6%	0.4%	5.2%	5.6%
% of total final energy demand in white paper scenario (14,206 ktoe ≈595 PJ)	0.3%	11.2%	11.6%	0.2%	2.5%	2.7%

[a] The average specific fuel consumption of new cars on the road in Ireland in 2006 was 2.3 MJ/km and the combined average mileage for petrol and diesel cars was 16,985 km/a [14], giving and average annual vehicle consumption of approximately 39 GJ/a.

respectively [65,66]; the quantity of biomethane in Sweden is on an upward trajectory. A recent study by the British Gas Board [67] suggested base and stretch case scenarios for 2020 of 5% and 18% substitution of total UK gas demand of 97 billion cubic metres. An objective of this paper is to ascertain levels of substitution for Ireland. With reference to Table 8 this paper generates ‘practical energy’ and ‘potential energy’ values of 7.5% and 33.2% substitution of total Irish gas demand. The elevated percentages are associated with the fact that the use of grass was not considered in the National Grid Report. Omitting grass the practical level obtained here is 1%. Of benefit to Ireland in the area of organic wastes is the elevated ratio of cattle to people. Ireland has the highest ratio of cattle to human population in the EU-27, almost 3.5 times that of the next highest country, Luxemburg (calculated from 2007 data in [68,69]). Ireland also has the fifth highest ratio of cattle to human population in the world after Uruguay, New Zealand, Botswana and Paraguay (calculated from 2007 data in [70]; and 2008 data in [71]).

5.2. Slurry digesters at farm scale or CAD scale

The biogas/biomethane industry is different in different countries. For example Austria, Bavaria and Eastern Germany have adopted a large number of farm scale digesters [61]. Denmark on the other hand embraced centralised anaerobic digestion (CAD); there are of the order of 20 such facilities in Denmark, a country not dissimilar in size and population to Ireland [72]. The CAD facilities operate in the range of about 20,000–80,000 t/a of feedstock. For 2020 the authors have assessed a practical level of 1.88 PJ/a from 3.87 Mt/a of feedstock.

5.3. Grass digesters

If 97,500 ha of grass are digested the annual feedstock is 5.3 Mt/a, based on a grass silage yield of 12 tDS/ha/a (the dry solids (DS) content of pit silage is 22%). This is a significant quantity of feedstock. The authors have visited a digester in Austria which digested 150 ha of grass; thus 650 of these could be constructed in Ireland. If we consider Germany with 3500 digesters and Austria with 600 digesters this is not outside the bounds of possibility.

5.4. Rural farm/CAD digesters

The authors propose economies of scale to allow financial feasibility in upgrading biogas to biomethane. Thus the CAD model is proposed and furthermore it is suggested that the smallest digester would be of the order of 50,000 t/a. The suggested feedstocks are grass and slurries. The national ratio is 1.37: 1. If an industry is proposed based on facilities treating 50,000 t/a of feedstock, then the base model would have feedstock comprising 29,000 t/a of grass and 21,000 t/a of slurry. This equates to 532 ha of grass and a 1438 sow unit pig farm (1 sow = 10 pigs @ 4 l slurry/day). The digestate from such digesters would be applied to the land from where the grass was cut; this will greatly reduce the requirements for mineral fertilizer as outlined by Smyth et al. [7]. This model would require 183 such facilities to utilize the 5.3 Mt/a of grass and 3.87 Mt/a of slurry (Table 9). It is estimated by the authors that a typical facility would cost of the order of €7 million [73].

The rural digester industry will develop with great influence from policy, incentives and leaders. CAD multi-feed systems may dominate as in Denmark with the size of the digester dictated by the quantity of feedstock within a certain catchment, for example a 20 km radius to minimize transport costs. On the other hand the rural farm scale system may dominate as in Germany or more than likely a bit of both will prevail. The authors strongly believe that “the pen is mightier than the sword” and would recommend a green energy policy to promote the utilization of biomethane at CAD scale.

Table 9
Digesters proposed for Ireland in 2020.

Digester type	Number	Feedstock treated	Total feedstock	Capital Investment (M€)[a]
Rural	183	50,000 t/a: 29,000 t/a grass (530 ha) 21,000 t/a slurry	9.15 Mt/a: 5.3 Mt/a grass (97 kha) 3.87 Mt/a slurry	183 × €7 = €1281
Slaughter	4	52,000 t/a	208,000 t/a	4 × €15 = €60
Municipal	4	54,500 t/a	218,000 t/a	4 × €20 = €80

[a] Capital costs from Murphy and Power [41], case study of Linkoping Digester, Murphy and McCarthy [73].

Table 10
Land required to provide equivalent biofuel energy to residues in 2020 (4.3 PJ/a) with different energy crop scenarios.

Biofuel	Crop (t/ha)	Fuel/t	Fuel/ha/a	Gross energy (GJ/ha/a)	Land required (kha)	Rotation	Land contracted (kha)
Rapeseed biodiesel[a]	4	0.3 t	1.2 t oil	46	93	1 in 5	465
Sugar beet ethanol[b]	50	100 l	5000 l	105	41	1 in 3	123
Wheat ethanol[b]	8.4	375 l	3150 l	66	65	2 in 3	98
Sugar beet biogas[b]	50	128 m^3	6400 m^3	134	32	1 in 3	96
Wheat biogas[b]	8.4	420 m^3	3528 m^3	74	58	2 in 3	87
Grass biogas[c]	55	107 m^3	5891 m^3	122	35	Grown every year	35

[a] From Thamsiriroj and Murphy [6].
[b] From Murphy and Power [20].
[c] From Smyth et al. [7].

5.5. Slaughter waste digesters

The authors have estimated that by 2020, a quantity equivalent to 208,000 t/a of slaughter waste may be digested. This is about 5% of the quantity estimated for slurry in CAD facilities. Two routes may be explored. One route is transportation of slaughter waste to these CAD facilities. This however necessitates pasteurisation of feedstocks and the mixing of feedstocks which may not be of similar hygiene standards. This may have a knock on effect on land application of digestate. Typically slaughter waste must be ploughed into arable land for cereal production; while digestate from slurry and silage may be land applied to pasture. As Ireland has a low proportion of arable land under cereals (less than 9%) it is preferable to separate the feedstocks. Thus preferred route is for four large facilities such as Linkoping, Sweden treating 50,000 t/a of slaughter waste. The authors estimate a capital cost of €15 million for each facility based on similar facilities visited.

5.6. Municipal digesters

The authors estimate that 218,000 t/a of OFMSW will be digested in 2020.Typically for each person in the country about 180 kg of OFMSW is generated. Thus a 50,000 t/a facility would equate to a population equivalent of 277,000. This is readily attainable in Dublin (population of greater Dublin about 1 million) and Cork (City and county have a population of 400,000). Thus the authors would expect 4–5 facilities at a scale of approximately 50,000 t/a. These facilities would have an expected capital investment of up to €20 million each [41]. The exact cost would depend on the technology provided.

5.7. Biodiesel plants

As discussed in Section 4.6 the existing facility in New Ross has the capacity to utilize the practical obtainable level of used cooking oil and tallow. This would result in not processing rapeseed at the facility.

6. Land-take

The aim of this paper is to propose a biofuel strategy for Ireland that minimizes land-take. The use of residues for energy does not require agricultural land and has the added benefit of providing sustainable waste management. The energy potential of residues to produce biofuels is estimated as 4.3 PJ/a in 2020 (Table 8). If this energy were to be provided by rapeseed biodiesel, 93 kha (23% of Irish arable land) would be needed under oilseed rape and, as the crop is generally grown in a 1 in 5 year rotation, a total of 465 kha (116% of Irish arable land) would be required under contract (Table 10). Other energy crops grown in rotation include wheat ethanol and sugar beet biogas, which would require 98 and 84 kha under contract, respectively (Table 10). The potential of residue-based biofuels to minimize land-take is clear.

Of the Irish energy crops reviewed in Table 10, grass has a significantly lower land-take than the alternatives. In addition, the area of grassland proposed for energy use in this paper is likely to be surplus to future agricultural requirements (if NCCS recommendations are implemented), and will therefore not require substitution of food production or land use change. For the biofuels strategy outlined in this paper comprising the use of residues and surplus grass, the practical energy in 2020 is calculated as 16.2 PJ and requires the use of 97.5 kha of grass. If this energy were to be provided solely by rapeseed biodiesel, a total of 352 kha would be required (or 1760 kha under contract).

7. Conclusions

Anaerobic digestion has seen a resurgence of interest due to its potential for manure stabilization, sludge reduction, odour control, and energy production [74]. Ireland has significant sources of organic waste/residues in the form of agricultural slurry, OFMSW, UCO, slaughterhouse waste, tallow, etc., in addition to surplus grass.

The potential for energy generation from these feedstocks in 2020 is 68.8 PJ energy. This is sufficient to fuel about 1.7 million private cars (93% of present private car fleet), to replace more than 33% of natural gas, 20% of transport fuel and 10% of final energy demand (Table 8). The practical energy generation in Ireland by 2020 is 16.2 PJ. This is sufficient to fuel about 390,000 private cars (22% of present private fleet), to replace 7.5% of natural gas supply, 5.1% of transport fuel and 2.3% of final energy demand (Table 8).

For the practical energy case (Table 9) the authors suggest 191 digesters consisting of 4 slaughter facilities, 4 municipal digesters and 183 rural CAD facilities based on slurry and grass.

The paper seeks to minimize land-take associated with a biofuel strategy. If this quantity of biofuel were to be met with rapeseed biodiesel only, then 352,000 ha would be required under oilseed rape each year. This surplus grass/residue strategy equates to 97,500 ha/a under grass, which is only 28% of the land area that would be required under rapeseed. This is a significant saving of land.

It is essential that countries need to look foremost to residues to produce biofuels. Secondly they need to establish what is the optimal crop and technology best suited to that particular country's climate and agricultural practice. The path of least resistance, importing biofuel technologies and practices from other countries is not always the best path to take. This paper would suggest that rather than following the rapeseed biodiesel, grain ethanol scenarios utilized in Europe, Ireland is best suited to employing readily available digestion technologies to a range of feedstocks ubiquitously available in Ireland; slurry, slaughter waste, and grass.

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